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Detached Eddy Simulation of Blade-Pod Interactions

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Abstract: For the tractor type podded propulsor there is a strong interaction between propeller wake and pod housing, which would cause fluctuation of pod housing forces, even lead to cavitation on pod housing. In this paper, the DES model is employed to simulate the interaction between propeller blade wake and the pod housing for a puller-type podded propulsor. The DES simulation results are compared with those from the RANS simulations using the same grid set. It is shown that propeller and propulsor performances obtained by the two methods are quite similar, however, turbulence model and grid density have a great effect on the average and unsteady fluctuation of pod housing lateral force. Stronger vortexes after propeller are simulated by DES model and fine grid. Especially, at downstream of strut and pod, vortex structures of DES model are more complex, and stronger flow separation happens at the end of strut, cause larger pressure fluctuation near the end of the strut.

1 INTRODUCTION

For the tractor type podded propulsor there is a strong interaction between propeller wake and pod housing, which would cause fluctuation of pod housing forces and vibration of propulsion, even lead to cavitation on pod housing.

The RANS method is the most used turbulence model in propeller performance numerical prediction. Many different numerical research about podded propulsion also choose RANS method[1-3].However, the usual approach of solving the RANS equations with k-ε or k-ω type turbulence models suffers from too much dissipation so that the trailing vortices, especially the tip vortex, attenuates quickly behind propeller trailing edges. On the contrary, the Detached Eddy Simulation (DES) turbulence model can track the vorticity field for a longer distance, which correlates better with experimental investigations[4], and has been used in a few of researches about propeller wake and its effect[5-7]. But few research use DES method in the CFD study of podded propulsion.

In this article, both DES and RANS simulations are carried out. Two grids with a grid coarsening factor of $\sqrt[3]{2}$ are used. Then propulsor performance and flow field around pod housing are compared.

2 MODELING APPROACH

A tractor-type podded propulsor is used for our investigation, the model geometry is shown in the left of figure 1. The computational domain is a circular cylinder, as shown in the right of figure 1, the diameter is five times of the propeller diameter. And this domain is divided into upstream and downstream sub-domains at the end of the rotating hub; the upstream domain rotates synchronously with the blades and the hub, while the downstream domain which contains the pod housing is stationary.

In the upstream domain, boundary layers grids are attached to blades and hub surface, and tetrahedral cells are used out of the boundary layers. Downstream domain containing the pod housing is discretized with hexahedral cells. H-grid topology is chosen around strut, while O-grid topology is chosen around pod and far flied.

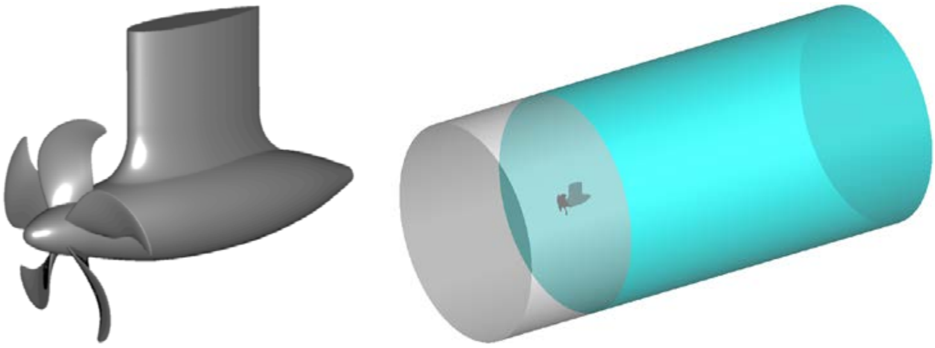


Figure 1: Model geometry and computational domain

For the grid effect study, two grids with a grid coarsening factor of $\sqrt[3]{2}$ are simulated, as as shown in figure 2. RANS and DES simulations are carried out at J=0.7. Unsteady solver is used in both RANS and DES simulation, with a time step of 0.005T. In the RANS simulation, RNG k-ε model and non-equilibrium wall function are employed for turbulence closure. And in the DES simulation, delay DES is chosen.

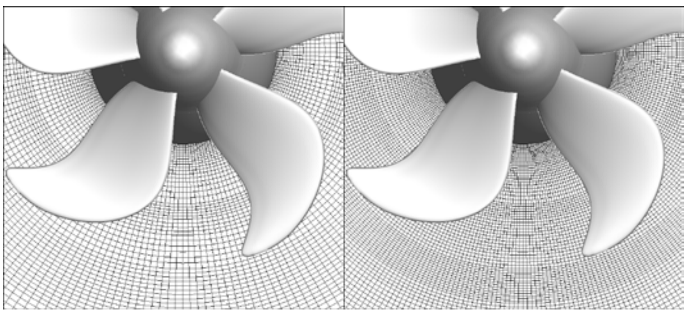


Figure 2: Grids in propeller wake

3 RESULTS AND ANALYSIS

3.1 Propulsor performance

The open water characteristics of podded porpulsor by different simulations cases are compared in figure 3. The left picture shows the average of the porpulsor characteristics. It is shown that turbulence model and grid density has little influence on the average of porpulsor characteristics. And the right picture shows the amplitude of the porpulsor characteristics. The unsteady fluctuation of characteristics by simulation of fine grid with DES turbulence model is stronger than the other three. But amplitudes of different simulations are all less than 5‰ of each average.

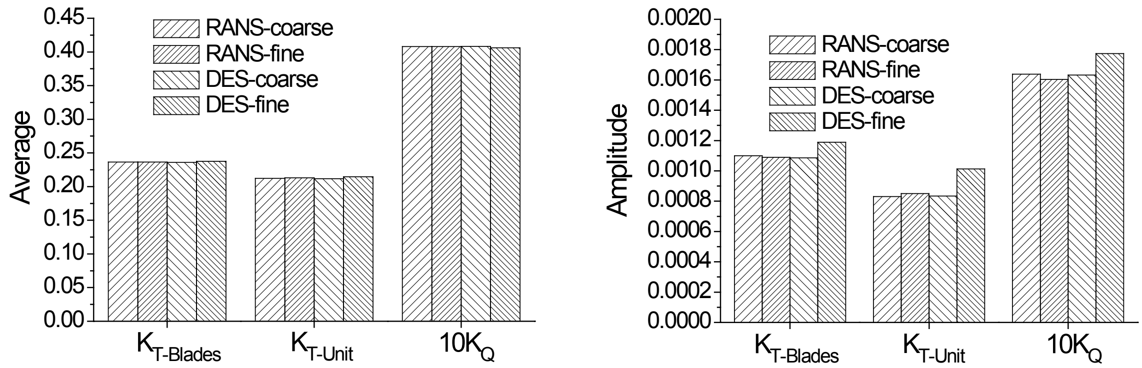


Figure 3: The open water characteristics, average (left), amplitude (right)

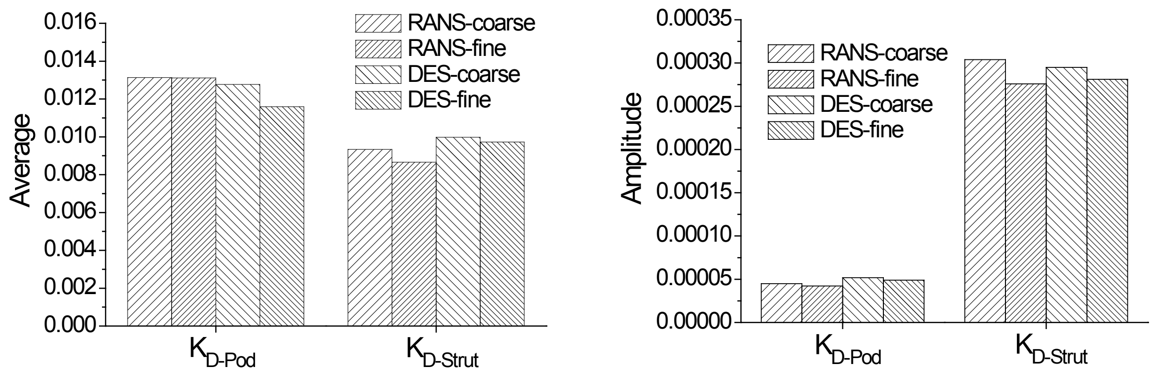


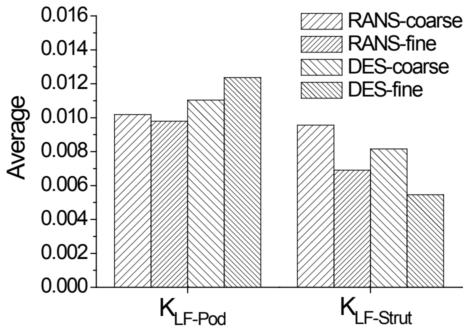
Figure 4: The resistance coefficients of pod and strut, average (left), amplitude (right)

Figure 4 shows the resistance coefficients K_D of pod and strut. Here, we define the resistance coefficient K_D as

$$K_D=R/\rho n^2 D^4 \tag{1}$$

where n is the propeller number of revolutions and D is the propeller diameter.

The pod and strut contribute nearly half and half to the total resistance of pod housing, but the unsteady fluctuation of strut resistance (about 4% of its average) is much stronger than amplitude of pod resistance (about 4‰ of its average). And For both pod and strut, finer grid would gain smaller resistances and amplitudes. For the pod resistance, DES simulation would gain smaller average, but larger amplitude. On the contrary, for the resistance of strut, DES simulation gains larger averages, but smaller amplitudes. However, since the unsteady fluctuation of pod housing is a small number to the propolsor thrust, differences from turbulence model and grid density have little effect on the porpulsor characteristics.



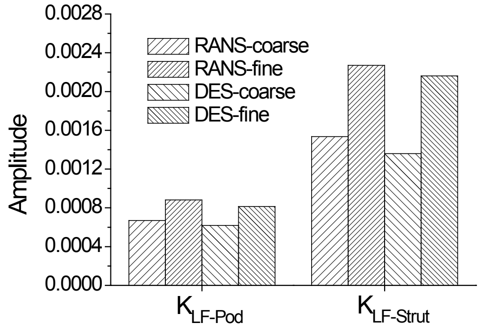


Figure 5: The lateral force coefficients of pod and strut, average (left), amplitude (right)

Figure 5 shows the lateral force coefficients K_{LF} of pod and strut. And we define the the lateral force coefficients K_{LF} as

$$K_{LF}=F_L/\rho n^2 D^4 \tag{1}$$

where F_L is the lateral force; n is the propeller number of revolutions; and D is the propeller diameter.

Turbulence model and grid density have a great effect on both the average and the unsteady fluctuation amplitude of pod housing lateral force. For the average of pod lateral force, result from DES simulation is larger than that of RANS simulation, especially for DES simulation and fine grid, its $K_{LF\text{-}Pod}$ is 20% larger than RANS simulation. For the average of strut lateral force, DES model and finer grid cause a smaller average; result from DES simulation is 8% less than that of RANS simulation, result from fine grid is 30% less than that of coarse grid. And then look at the unsteady fluctuation, for both of the lateral force of pod and strut, result from DES simulation is less than that of RANS simulation; and the increase of grid density result in a great increase of fluctuation amplitude, it is more obvious on the strut, the amplitude increase about 50%.

3.2 Flow field around pod housing

The interaction between propeller wake and pod housing not only cause the fluctuation of the propulsor performance, but also influence downstream flow field and pressure distribution on the pod housing. Figure 6 shows vortex structures as isosurfaces of Q=5000, and figure 7 shows the total vorticity magnitude at cross section of y=0. It is obvious that effect of grid density is much larger than that of turbulence model. The length of tip vortices solved with fine grid is almost twice of that solved with coarse grid. But we can still find that DES model can simulate stronger wake than RANS model, especially at downstream of strut and pod, vortex structures are more complex, stronger flow separation happens at the end of strut.

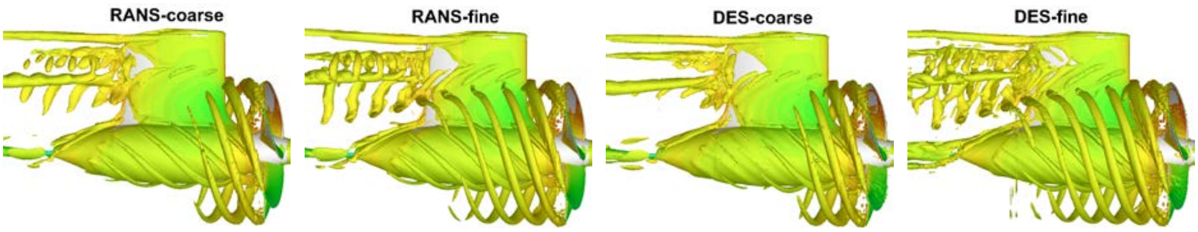


Figure 6: Vortex structures as isosurfaces of Q=5000

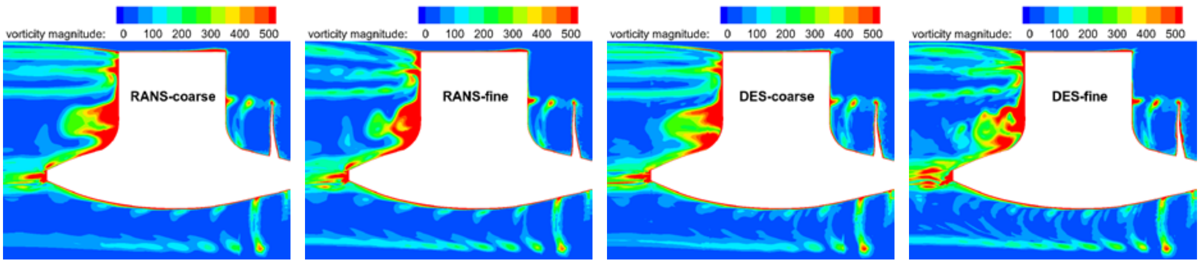


Figure 7: The total vorticity magnitude at cross section of y=0

To reseach the effect of tip vortexs on pressure distribution on the pod housing, we arrange a series of pressure monitor points on the strut. The specific arrangement of these monitor points is shown in figure 8. And here, we only simulate with fine grid.

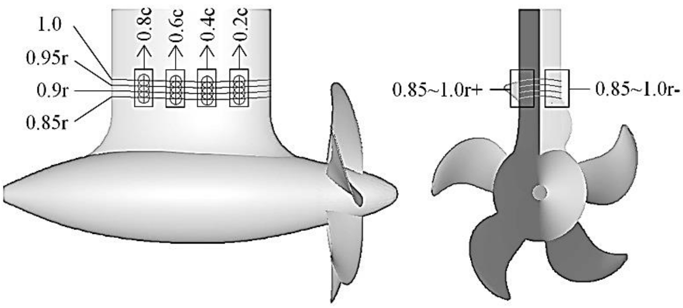


Figure 8: The arrangement of pressure monitor points on strut

Figure 9 shows the average and amplitude of pressure on strut monitor points. Comparing the results of DES and RANS model, on one side of strut (0.85~1.0r-), averages solved by

DES model are slightly larger than RANS model, on the other side (0.85~1.0r+), averages solved by DES model are slightly smaller than RANS model; and on most monitor points amplitudes solved by DES model are larger than RANS model, this is more obvious near the end of the strut.

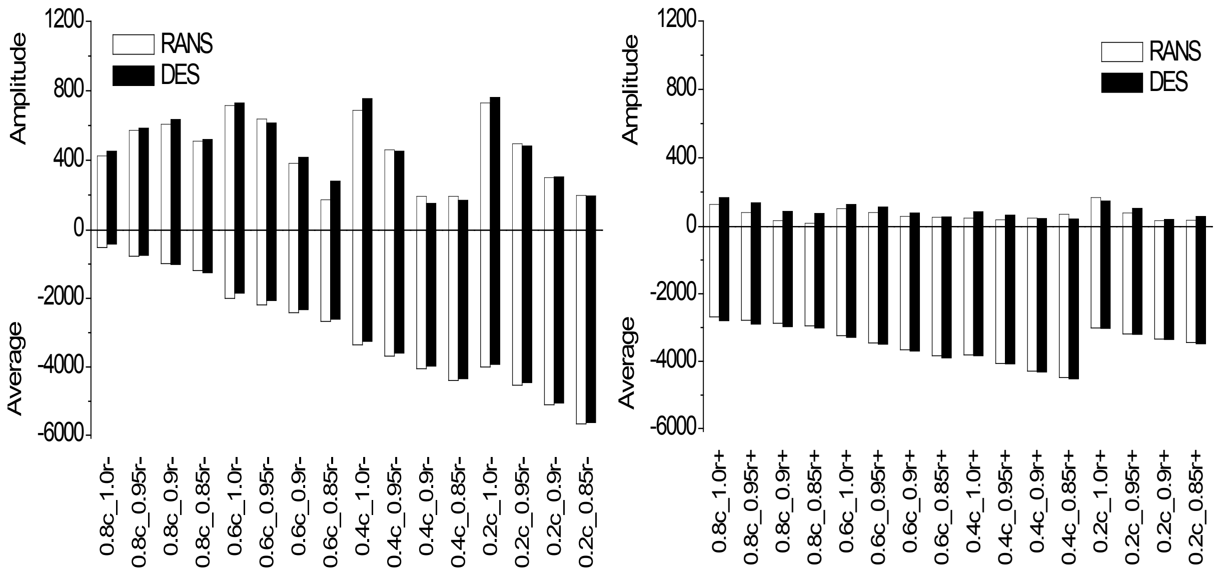


Figure 9: The average and amplitude of pressure on strut monitor points

4 CONCLUSIONS

To better study the interaction between propeller wake and pod housing, DES and RANS simulations are carried out. Two grids with a grid coarsening factor of $\sqrt[3]{2}$ are used. Then propulsor performance and flow field around pod housing are compared, and the following conclusions can be drawn:

- Turbulence model has little influence on the average of porpulsor open water characteristics. DES turbulence model with finer grid can simulate a stronger unsteady fluctuation of porpulsor open water characteristics. But the fluctuation amplitude is a small number to its average. Turbulence model and grid density have complex influence on resistance of pod housing, but these differences are small to porpulsor thrust.
- Turbulence model and grid density have a great effect on both the average and the unsteady fluctuation amplitude of pod housing lateral force. For the average, $K_{LF\text{-}Pod}$ by DES simulation with fine grid is larger than RANS simulation. And DES model and finer grid cause a smaller $K_{LF\text{-}Strut}$. For the amplitude, results of DES simulation is less than that of RANS simulation; and the increase of grid density result in a great increase of fluctuation amplitude, it is more obvious on the strut, the amplitude increase about 50%.

- For the flow field of propeller wake, effect of grid density is much larger than that of turbulence model. The length of tip vortices solved with fine grid is almost twice of that solved with coarse grid. And comparing the two turbulence model, DES model can simulate stronger wake than RANS model, especially at downstream of strut and pod, vortex structures of DES model are more complex, and stronger flow separation happens at the end of strut, cause larger pressure fluctuation near the end of the strut.

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